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Pathfinding Based on Edge Detection and Infrared Distance Measuring Sensor

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Abstract: This paper proposes that pathfinding for mobile robots, in unknown environment, be based on extracting 3D features of an object using 2D image edge detection and infrared (IR) distance measuring sensor. Standard VGA color camera gives very good results only in environment that is very well illuminated. Our solution is based on IR camera which enables robot to navigate between obstacles even in complete darkness.

Keywords: path finding, edge detection, Sobel

1 Introduction

The purpose of this project is to design an autonomous robot that can navigate from point A to point B in any environment.

2 Methods

As technology is progressing, people tend to use more and more intelligent machines and devices which will lighten their daily chores and responsibilities. It is common knowledge that such devices are capable of performing a limited set of tasks and are only as 'intelligent' as their programmers. There are endless possibilities for the application of these intelligent automotive systems, with the demand constantly on the rise.

The complexity of real world environments is still a challenging problem. Uneven out-door environments, dynamic objects, cluttered scenes and the absence of simple features are known problems. Most navigation systems presented up to now use 2D sensors like laser or sonar in combination with a 2D map for localization and path planning.

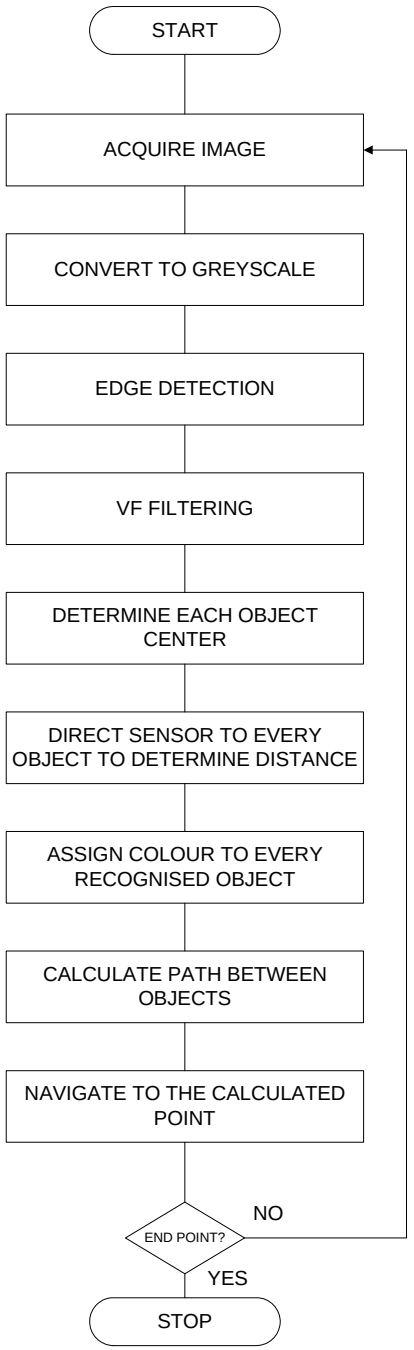

Figure 1
Algorithm for navigation

Current implementations using 3D data for robot navigation can be divided into three groups as in [1]:

- One group of systems used for outdoor navigation build full 3D models of the environment.
- Another approach is based on extraction of features like walls and tree trunks from the 3D data.
- The third approach combines 3D perception and a 2D map representation by use of virtual 2D scans. These virtual 2D scans, which are generated from 3D raw data, can be used as input data for already existing 2D navigation algorithms.

In this paper the third method was used.

Edge detection was realized with Sobel algorithm and distance measurement was done by Sharp's infrared sensor. Figure 1 shows an algorithm which is used for path finding. First-order derivatives in an image are computed using the gradient as in [3]. First-order derivatives of a digital image are based on various approximations of the 2D gradient. The gradient of an image f(x,y) at location (x,y) is defined as the vector:

$$\nabla f = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix} \tag{1}$$

It is well known from vector analysis that the gradient vector points in the direction of maximum rate of f at coordinates (x,y).

An important measurement in edge detection is the magnitude of this vector, denoted ∇f , where

$$\nabla f = mag(\nabla f) = \left[G_x^2 + G_y^2 \right]^{\frac{1}{2}} \tag{2}$$

This quantity gives the maximum rate of increase of f(x,y) per unit distance in the direction of ∇f .

The direction of the gradient vector is also an important measurement. Let $\alpha(x, y)$ represent the direction angle of the vector ∇f at (x,y). Then, from vector analysis,

$$\alpha(x, y) = \tan^{-1}\left(\frac{G_y}{G_x}\right) \tag{3}$$

where the angle is measured with respect to the x-axis. The direction of an edge at (x,y) is perpendicular to the direction of the gradient vector at that point.

Computation of the gradient of an image is based on obtaining the partial derivatives $\frac{\partial f}{\partial x}$ and $\frac{\partial f}{\partial y}$ at every pixel location. A 3x3 pixel area will be used to represent gray levels in the neighborhood of an image. One of the easiest ways to implement a first-order partial derivative at point z5 is to use following:

$$G_x = (z_7 + 2 * z_8 + z_9) - (z_1 + 2 * z_2 + z_3) \tag{4}$$

$$G_y = (z_3 + 2 * z_6 + z_9) - (z_1 + 2 * z_4 + z_7) \tag{5}$$

A weight value of 2 is used to achieve some smoothing by giving more importance to the center point, so the result is:

$$\begin{pmatrix} z_1 & z_2 & z_3 \\ z_4 & z_5 & z_6 \\ z_7 & z_8 & z_9 \end{pmatrix}$$

$$\begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

These are called Sobel operators. The Prewitt and Sobel operators are among the most used in practice for computing digital gradients. Prewitt masks are simpler to implement than the Sobel masks, but later the latter have slightly superior noise suppression characteristics, an important issue when dealing with derivatives. Note that the coefficients in all masks show a sum of 0, indicating that they give a response of 0 in areas of constant gray level, as expected of a derivative operator.

The masks discussed above are used to obtain the gradient components Gx and Gy. Computation of the gradient requires that these two components be combined. However, this implementation is not always desirable because of the computational burden required by squares and square roots. An approach used frequently is to approximate the gradient by absolute values:

$$\nabla f \approx |G_x| + |G_y| \tag{6}$$

This equation is much more attractive computationally, and it still preserves relative changes in gray levels. The trade-off for this advantage is that the resulting filter will not be isotropic (invariant to rotation) in general. However, this

is not an issue when masks such as Sobel masks are used to compute Gx and Gy. These masks give isotropic results only for vertical and horizontal edges.

If we combine Gx and Gy than we can also detect diagonal edges with following masks:

$$\begin{pmatrix} z_1 & z_2 & z_3 \\ z_4 & z_5 & z_6 \\ z_7 & z_8 & z_9 \end{pmatrix}$$

$$\begin{bmatrix} 0 & 1 & 2 \\ -1 & 0 & 1 \\ -2 & -1 & 0 \end{bmatrix} \begin{bmatrix} -2 & -1 & 0 \\ -1 & 0 & 1 \\ 0 & 1 & 2 \end{bmatrix}$$

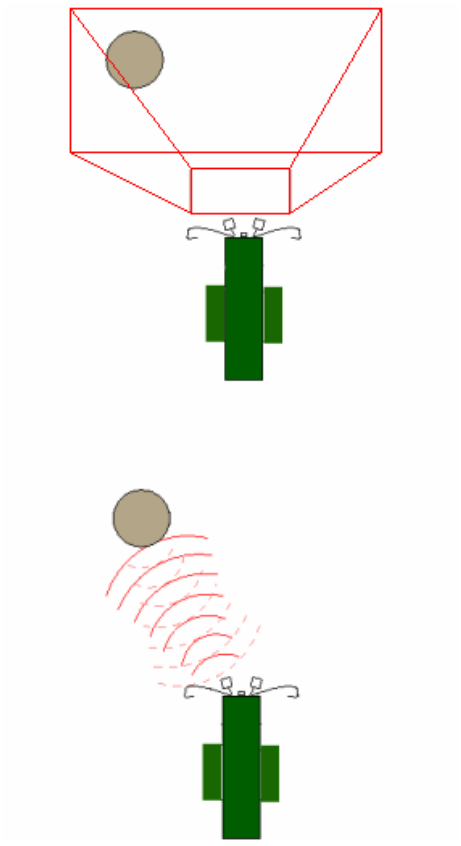

Figure 2
Phases of object detection

Figure 2 gives an overview of object recognition phases. In first phase the robot captures an image of its surrounding and processes that image in order to extract object. In the second phase the robot uses infra red sensor to determine distance between the robot itself and the obstacle. Figure 3 shows a color image taken by the robot. In this example there are two obstacles in front of the wall. Figure 4 presents the same image after edge detection and VF filtering. Figure 5 is the image with recognized objects. Each color represents different objects and distances.

Figure 3
Image taken from the robots camera

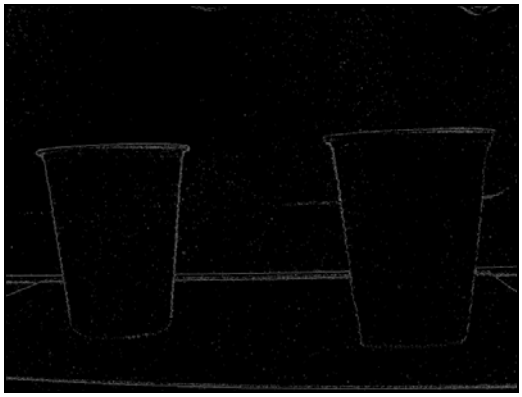

Figure 4
Result of the Sobel algorithm

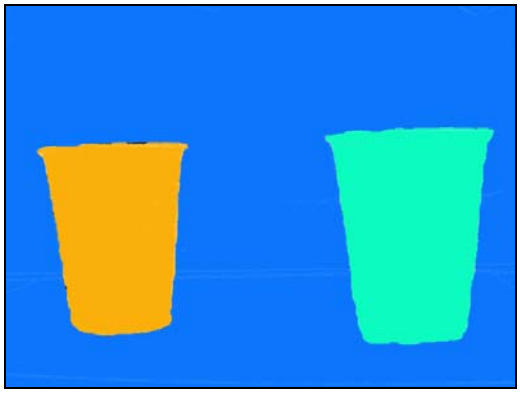

Figure 5
Object recognition

3 Distance Measuring

For distance measuring we used an analog IR sensor GP2D120 from Sharp. The maximum range for this sensor is 40 cm, but there are sensors that have a range of up to 160 cm. Since GP2D120 is an analog sensor there were four problems that needed to be overcome:

- output voltage level adjustment
- A/D conversion
- calibration
- mathematical function fitting of an sensor output curve

Interpreting the output of the sensor as distance required a significant amount of research. The distance measured by the sensor is continuously reported as a voltage which is converted by the processor to a digital number. Points had to be plotted in order to find the relationship between the reported voltage and the distance observed by the sensor. By referencing the data sheet for this sensor and developing equations for the best fit curve, we were able to use the sensor to report actual distances.

Sensor output curve fitting is presented in Figure 6.

The robot can also perform 3D mapping of its surrounding space, which means that it can memorize its previous positions.

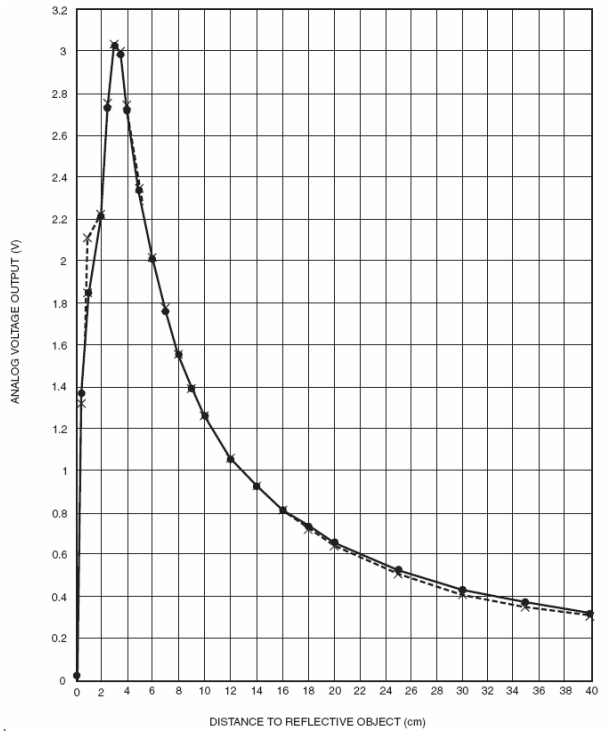

Figure 6
Sensor output curve fitting

4 Further Improvements

This model will achieve very good results if the environment is well illuminated. Also for the best results every object must consist of a single color.

Therefore, in the case of an ordinary color camera, it is obvious that this approach has two major problems:

- poor illumination of objects makes their recognition very difficult because edges cannot be detected,
- objects whose surfaces are covered with various color patterns are recognized as multiple independent objects, which means than in this case a stronger processor with more memory is necessary.

In case an ordinary color web camera is used the first problem could be solved with the use of a small lamp mounted on the robot. Unfortunately for a good illumination of a robot's environment we need a lot of power which could only be

obtained from external power supply. Of course, if external power supply is used, the robot's mobility would be severely compromised.

Further complications could occur if the robot was used in situations where artificial light is not allowed, for example in security agencies for burglary detection. For this reason, huge efforts have been made to develop mobile robots equipped with various sensors for military and public security and surveillance applications.

A small force of guards patrolling an area with flashlights and batons, on the lookout for trouble was a model that worked well enough over the years in the past. Today, the convergence of intelligent sensors, embedded systems, streamlined remote control mechanisms and applications promises to reduce the risk as well while tightening security. Instead of using sensors fixed to one location such as motion detector, window-break detector, and surveillance cameras which are limited to their built-in sensing ranges, it would be far better to use remotely controlled robots to patrol the area, spot anomalies, and notify security personnel over a wireless network or via a hand held, PDA-like device, which are all possible and available technologies now [4].

The second problem could be solved with the introduction of more powerful processors and more memory, but that would lead to a significantly more complex design, higher price and greater power demand. Thus, yet again, the mobility of the robot would be compromised.

The infrared IR camera presents a far better option, which would successfully solve both problems. Since the IR camera is sensitive to IR light it was necessary to use IR diodes to illuminate obstacles. The IR diode has low power consumption, and can also work in pulse mode, external power supply is not necessary in this case. On the other hand, obstacles that are illuminated with IR light do not reflect light from the visible color spectrum, so from the IR camera's point of view all objects are single colored. This means that the process of identifying obstacles is greatly simplified so there is no need for a powerful processor and large memory.

5 IR Camera Construction

The conversion of a standard color web camera into an IR camera is not very complicated. There are two technologies used for VGA camera construction:

- CMOS (complementary metal oxide semiconductor)
- CCD (charge coupled device)

In both cases the video chips are sensitive not only to rays from the visible spectrum of light, but also to rays from the IR spectrum of light.

The reason why web cameras are sensitive only to rays from the visible spectrum of light lies in the IR filter which is placed between the camera lenses and the video chip. The filter itself is made out of a thin piece of glass which is covered with a thin chemical layer. The substance used for layer absorbs IR rays and pass through rays from the visible spectrum of light. In order to complete the conversion it is required to remove the IR filter and substitute it with a color filter. The color filter will absorb the visible light but it will pass the IR light. A very good solution for the color filter is a piece of ordinary film negative from a 35 mm photo film. It must be a color negative, because black and white one won't work.

6 Practical Results

The following example compares the results taken from the color and IR camera.

Figure 7 shows the picture taken by web camera where the IR filter was applied. It is obvious that the existence of color pattern on the person's shirt led to false object identification which is clearly visible in Figure 8.

Figure 9 presents the same scenery taken by the same web camera only this time with the color filter applied. Since there are no color patterns on the objects this time, the edge detection algorithm has recognized much less false objects than in the previous case which is demonstrated in Figure 10. False objects are the result of shadows and could be reduced by higher IR illumination.

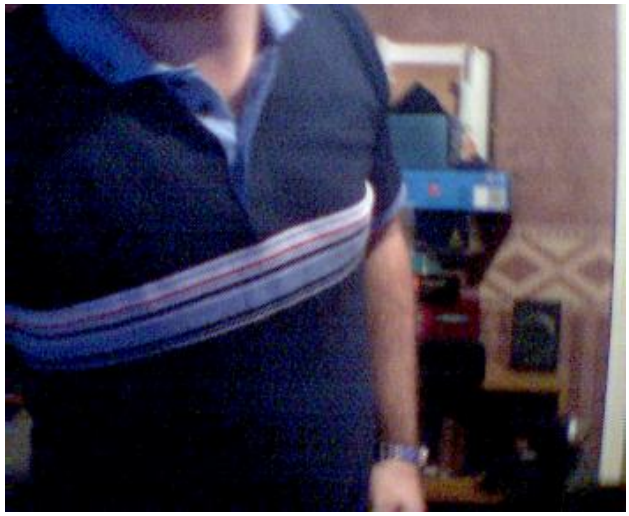

Figure 7
Color picture

Figure 8
Recognized objects in the color picture

By comparing Figure 8 and Figure 10 it can be concluded that the IR camera detected far less false objects than the color camera and therefore represents a much more feasible solution for obstacle detection.

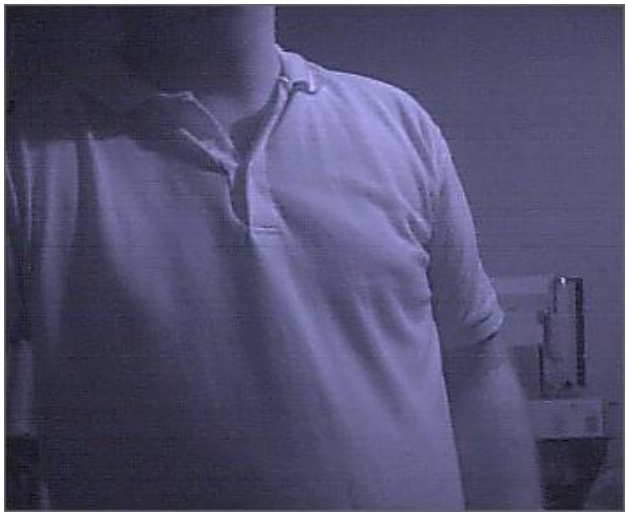

Figure 9
Infrared picture

Pictures presented in Figures 7 and 9 were taken by Geoff Johnson for testing purposes [5].

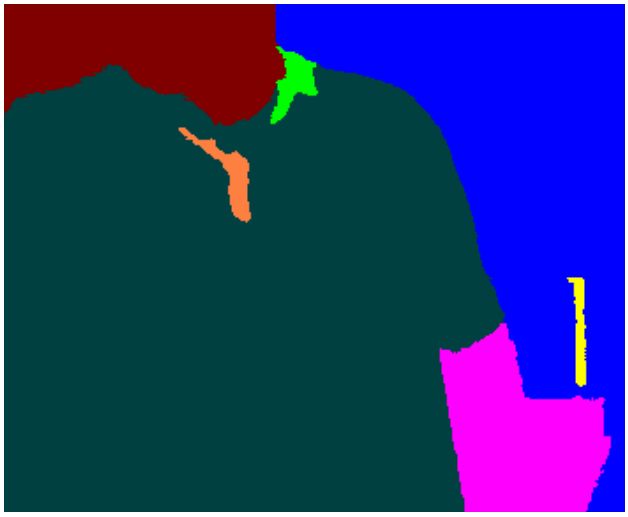

Figure 10
Recognized objects in the infrared picture

7 Navigation Strategy

Path navigation between the starting point and end point is rather straightforward as in [6].

There are five specific phases which can occur during path navigation:

- Path predetermining state, the system must be pre-limited for going straight distance, turning left or right and returning back straight to the starting point for no obstacles condition.
- Obstacle avoiding state (obstacle is at the front). The system must be stopped for a while. It must turn to the left and check if there is any obstacle or not in this turning state. And then it will return to the right and go straight at normal line.
- Obstacle is detected at the left. The system must be stopped for a while to calculate the next best path. The system must turn to right and check if there is any obstacle or not in this turning state. It must return to the left and go straight in a normal line.
- Obstacle is detected at the right. The system must be stopped for a while to calculate next best path. It must turn to the left and check if there is any obstacle or not in this turning state. And then it will return to the right and go straight in a normal line.

- Path is too narrow or the robot is stuck, the system must perform a rollback play – the robot must be returned in the previous point and choose a different path.

The generalized path navigation is given in Figure 11.

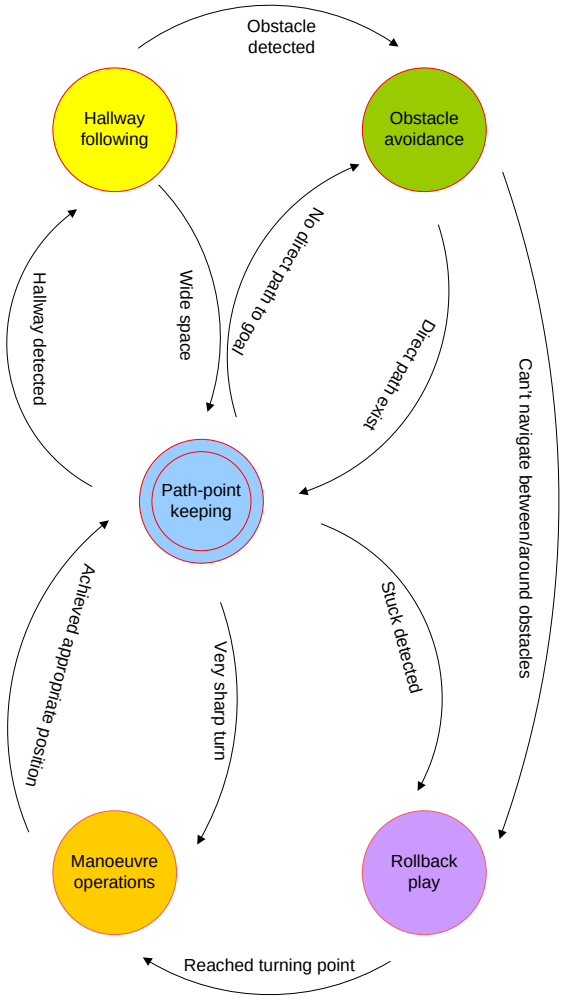

Figure 11
Recognized objects in the color picture

Conclusion

The combination of 2D images with IR sensors in order to extract 3D features of the surroundings has been proven a highly effective and economical solution for robot guidance. A standard color camera gave good results only in laboratory

conditions. This paper showed that in non laboratory conditions, especially in environments where people work, the IR camera produces better results. Since IR light is invisible for human eye the robot does not affect people's working efficiency. Further improvement is possible with the use of two IR cameras in order to achieve stereo vision.

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